Measurement of the Transverse Single Spin Asymmetries for π^0 and Electromagnetic Jets at forward rapidities at STAR

Mriganka Mouli Mondal (for the STAR Collaboration)

Texas A&M University

Outline

- ✧ Forward Meson Spectrometer in the STAR experiment
- ✧ Transverse Single Spin Asymmetries (TSSA)
- ✧ EM-Jets measured from FMS photons
- ✧ A_N at √s = 500 GeV and its correlation with midrapidity jets

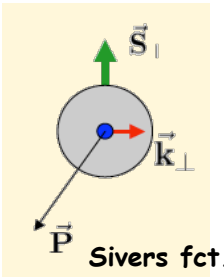
TSSA - 2 theoretical frameworks

Spin-dependent transverse momentum dependent (TMD) function $S_T.(Pxk_T)$
Brodsky, Hwang, Schmidt, 02
Collins, 02, Ji, Belitsky, Yuan, 02

+ Collins fragmentation functions

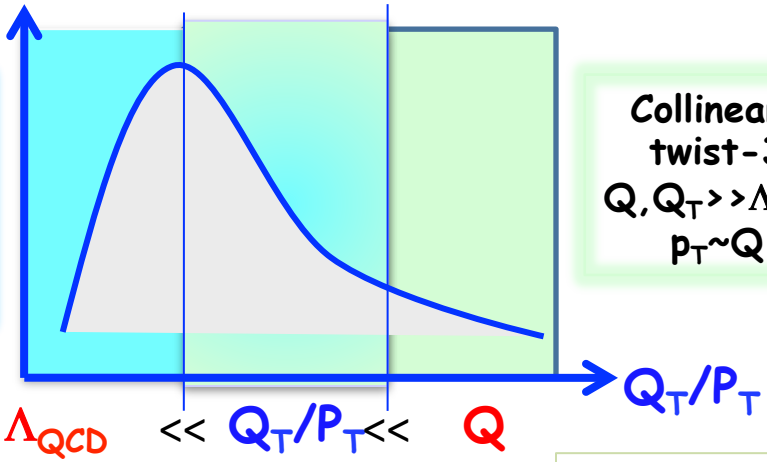
Twist-3 quark-gluon correlations
Efremov & Teryaev: 1982 & 1984
Qiu & Sterman: 1991 & 1999

+ Twist three fragmentation functions

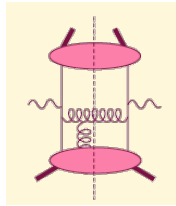


Sivers fct.

Transverse momentum dependent
$Q >> Q_T >= \Lambda_{QCD}$
$Q >> p_T$



Collinear/ twist-3
$Q, Q_T >> \Lambda_{QCD}$
$p_T \sim Q$


Efremov, Teryaev; Qiu, Sterman

Need 2 scales
Q^2 and p_t
Remember pp:
most observables one scale
Exception:
DY, W/Z-production

Need only 1 scale
Q^2 or p_t
But
should be of reasonable size
should be **applicable to most pp observables**
$A_N(\pi^0/\gamma/\text{jet})$

π^0 A_N Measurements at Forward Rapidity

Inclusive π0 production

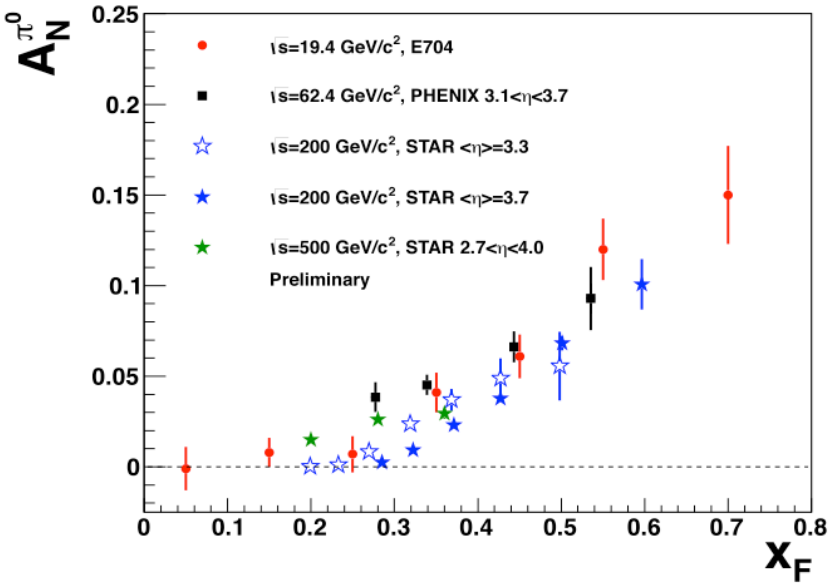
$$p_\uparrow + p \longrightarrow \pi^0 + X$$

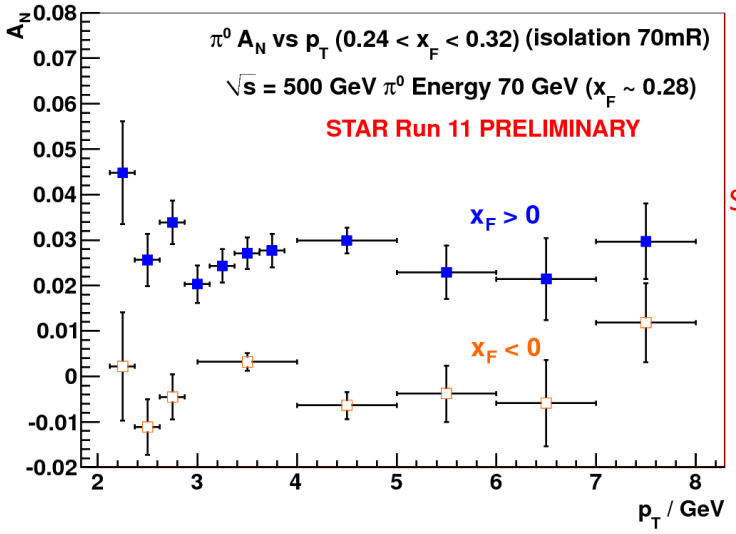
Transverse Single Spin Asymmetry

$$A_N \equiv \frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow}$$

$x_F = 2p_Z/\sqrt{s}$

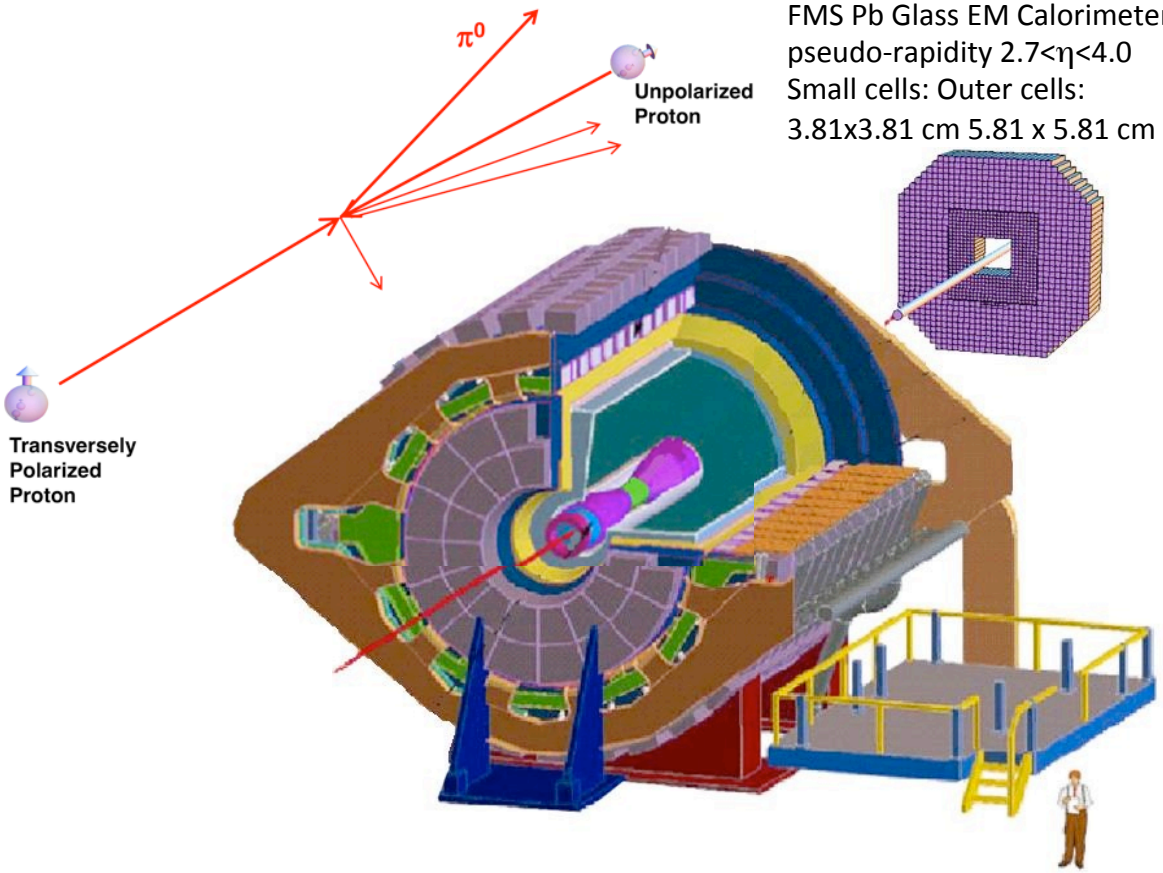
- Rising A_N with X_F
- A_N nearly independent of √s
- No evidence of fall in A_N with increasing P_T





CIPANP 2012, Steve Heppelmann

Forward ECAL in STAR



FMS Pb Glass EM Calorimeter
pseudo-rapidity 2.7<η<4.0
Small cells: Outer cells:
3.81x3.81 cm 5.81 x 5.81 cm

Forward Meson Spectrometer (FMS) :
-- Pb glass EM calorimeter covering 2.5< η <4.0
-- Detect π^0,η, direct photons and jet-like events in the kinematic region where transverse spin asymmetries are known to be large.

EM-Jet characteristics

p+p √s = 500 GeV transverse datasets

Jet algorithm : anti-kt

R-parameter : 0.7

$p_T^{EM\text{-}Jet} > 2.0$ GeV/c

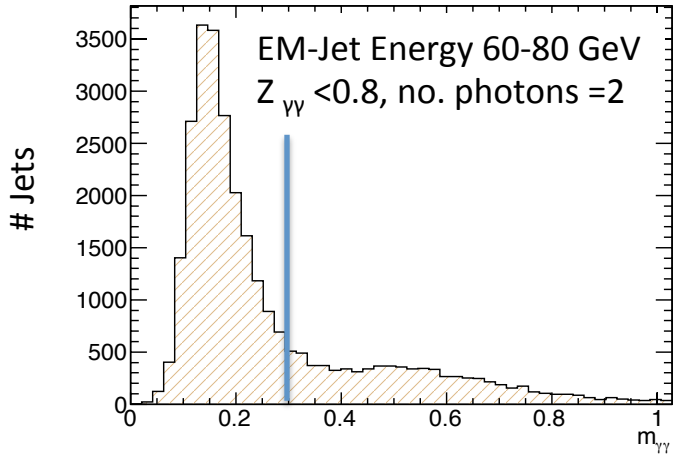
photons with $p_T > 0.001$ GeV/c

Leading EM-Jets :

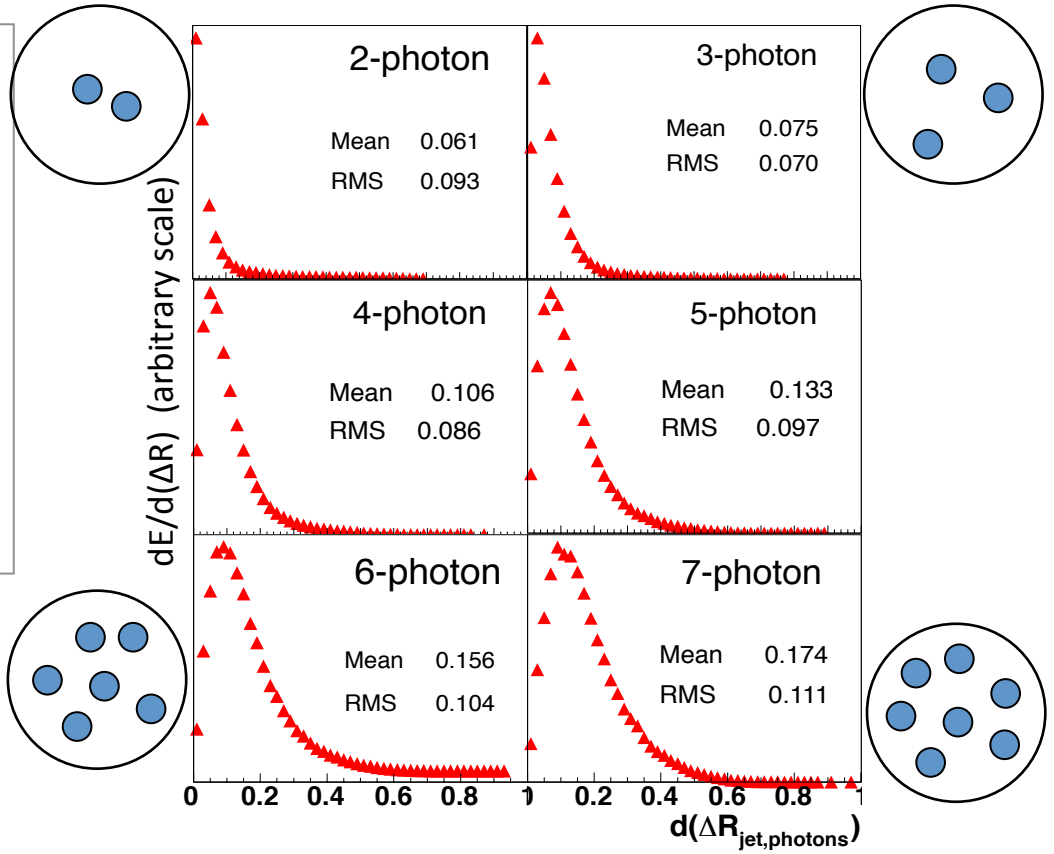
Multi-photon Jets with highest energy

$2.8<\eta^{EM\text{-}Jet}<4.0$

40 GeV < $Energy^{EM\text{-}Jet}$ < 100 GeV



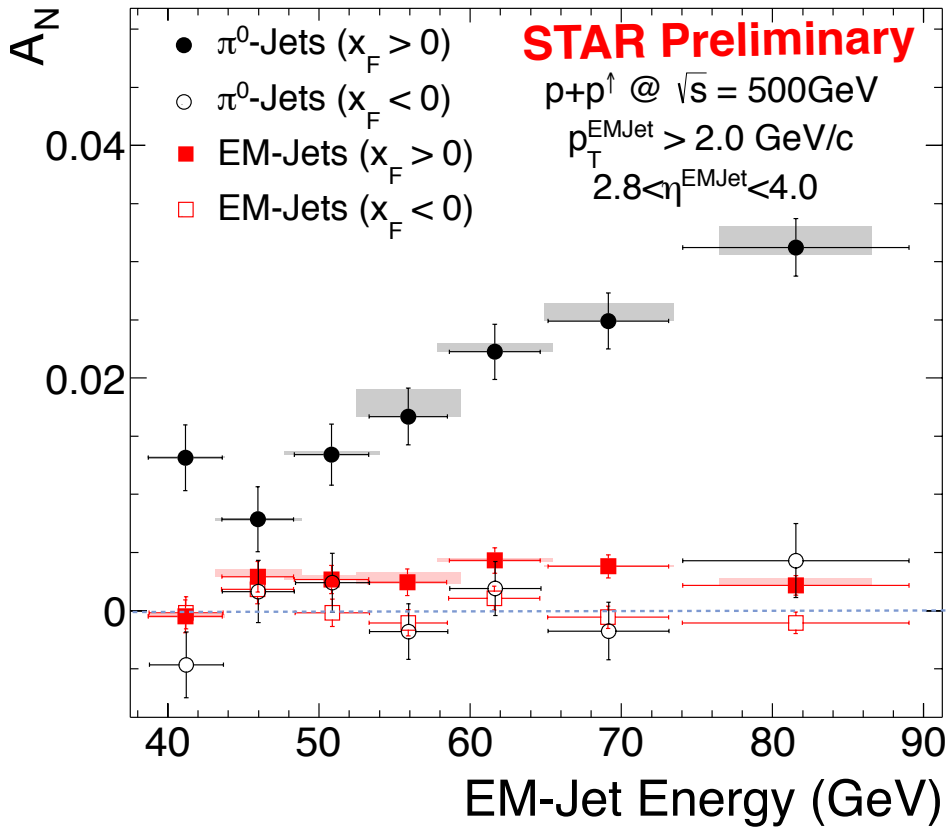
γγ invariant mass 2-photon EM-jets



dE/d(ΔR) distribution of EM-Jets

- 2-photon jets are mostly π^0
- Events with more than 2 photons show jet-like energy flow

A_N vs. EM-Jet Energy

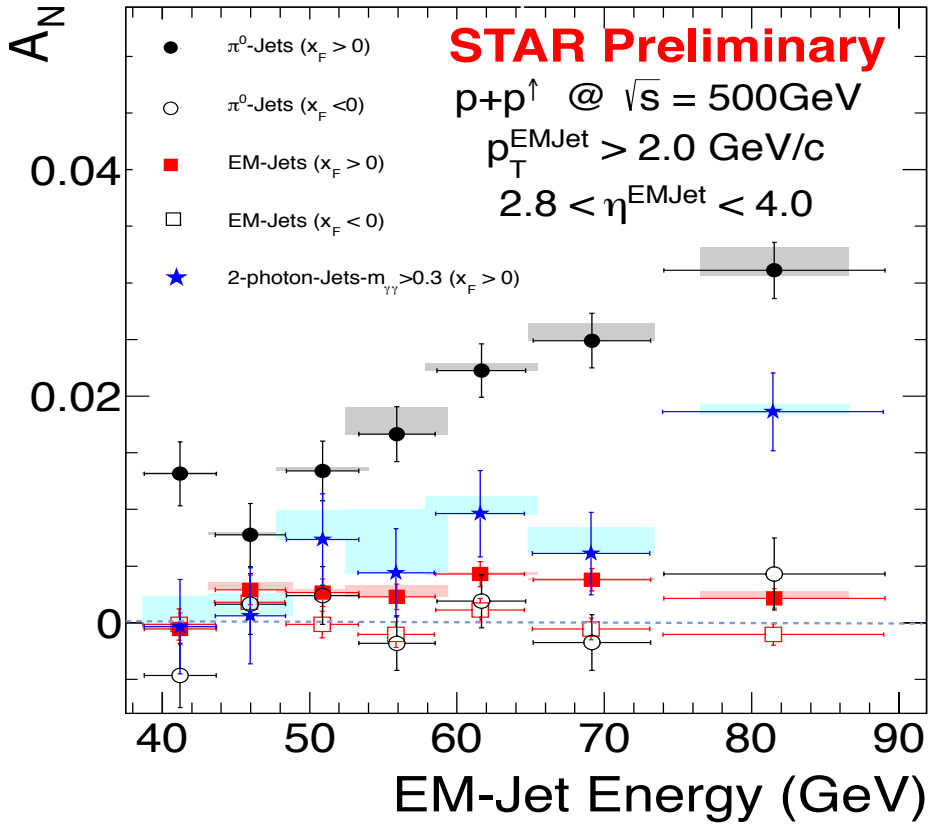


π^0-Jets –
2γ-EM-Jets with
$m_{\gamma\gamma}$ <0.3
$Z_{\gamma\gamma}$ <0.8

EM-Jets –
with no. photons >2

✧ Isolated π^0's have large asymmetries consistent with previous observation (CIPANP-2012 Steven Heppelmann)
https://indico.triumf.ca/contributionDisplay.pycontribId=349&sessionId=44&confId=1383
✧ Asymmetries for jettier events are much smaller

A_N vs. EM-Jet Energy



π^0-Jets –
2γ-EM-Jets with
$m_{\gamma\gamma} < 0.3$
$Z_{\gamma\gamma} < 0.8$

2γ-EM-Jets (η + continuum) –
with $m_{\gamma\gamma} > 0.3$

EM-Jets –
with no. photons >2

✧ Isolated π^0's have large asymmetries consistent with previous observation (CIPANP-2012 Steven Heppelmann)
https://indico.triumf.ca/contributionDisplay.pycontribId=349&sessionId=44&confId=1383
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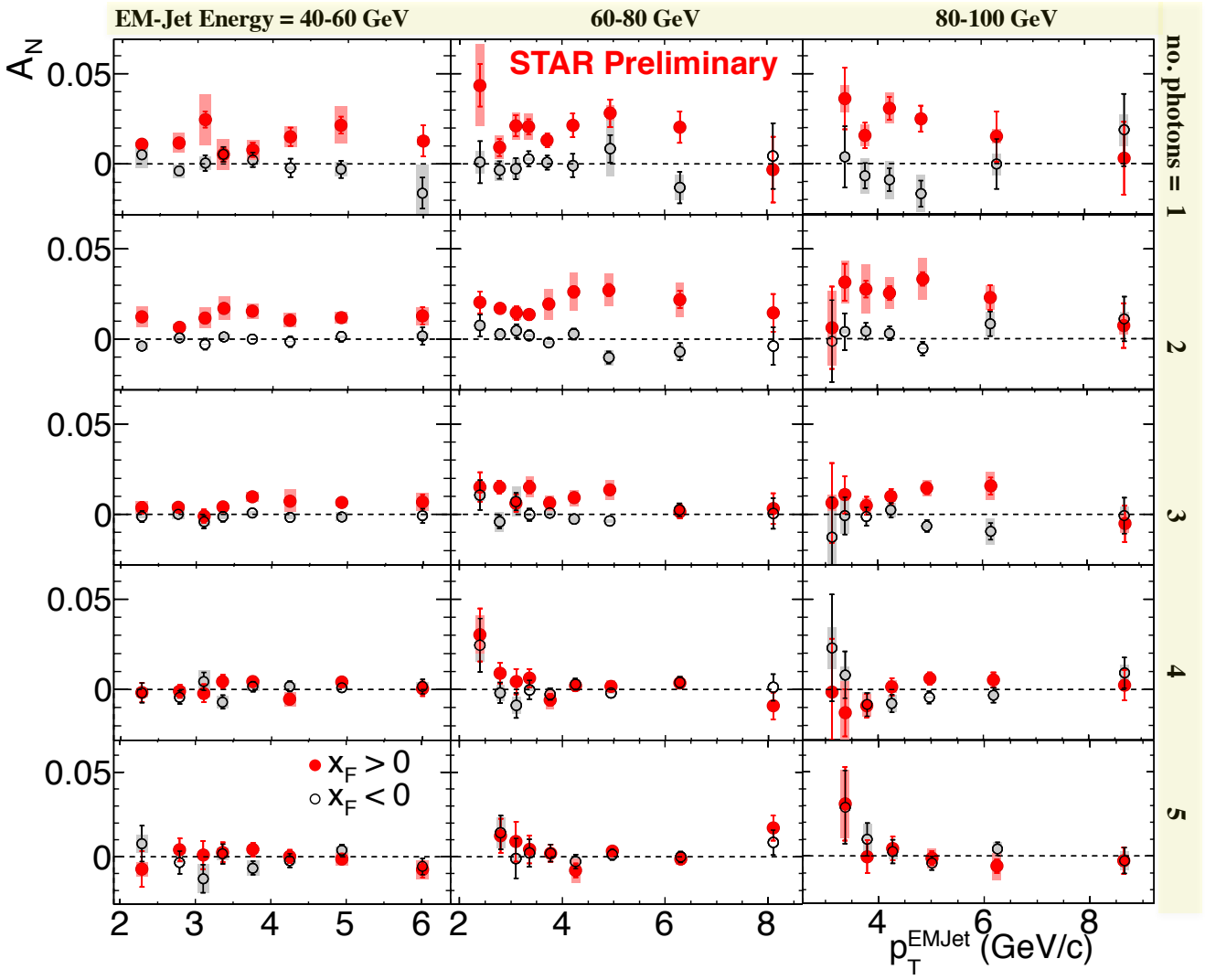
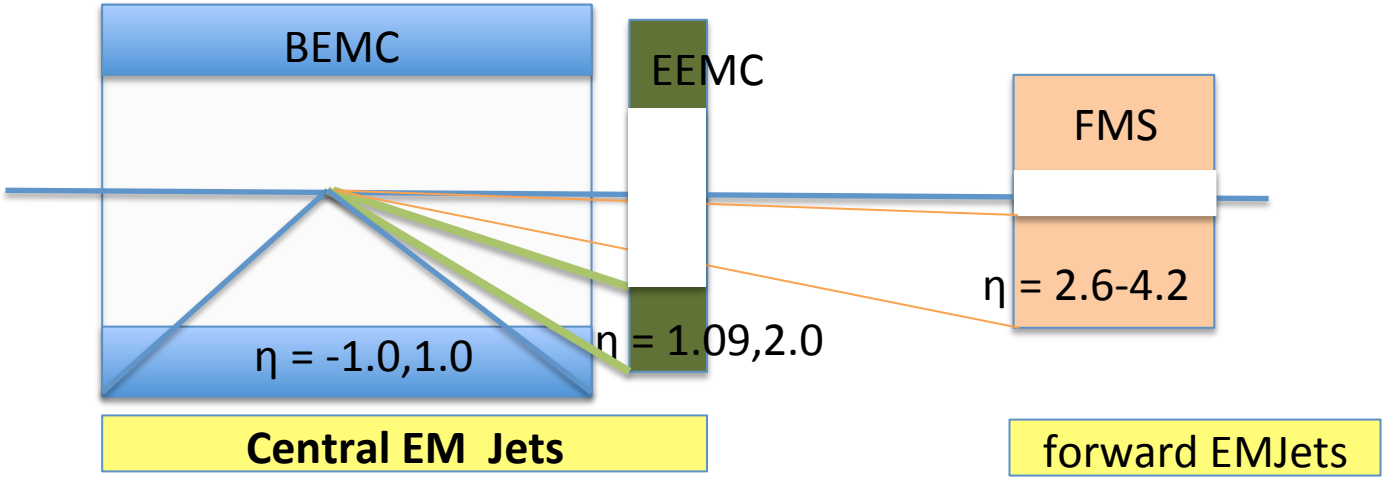
A_N for different # photons in EM-Jets



- 1-photon events, which include a large π^0 contribution in this analysis, are similar to 2-photon events
- Three-photon jet-like events have a clear non-zero asymmetry, but substantially smaller than that for isolated π^0's
- A_N decreases as the event complexity increases (i.e., the "jettiness")
- A_N for #photons >5 is similar to that #photons = 5

A_N with midrapidity activities



towers (BEMC+EEMC) :

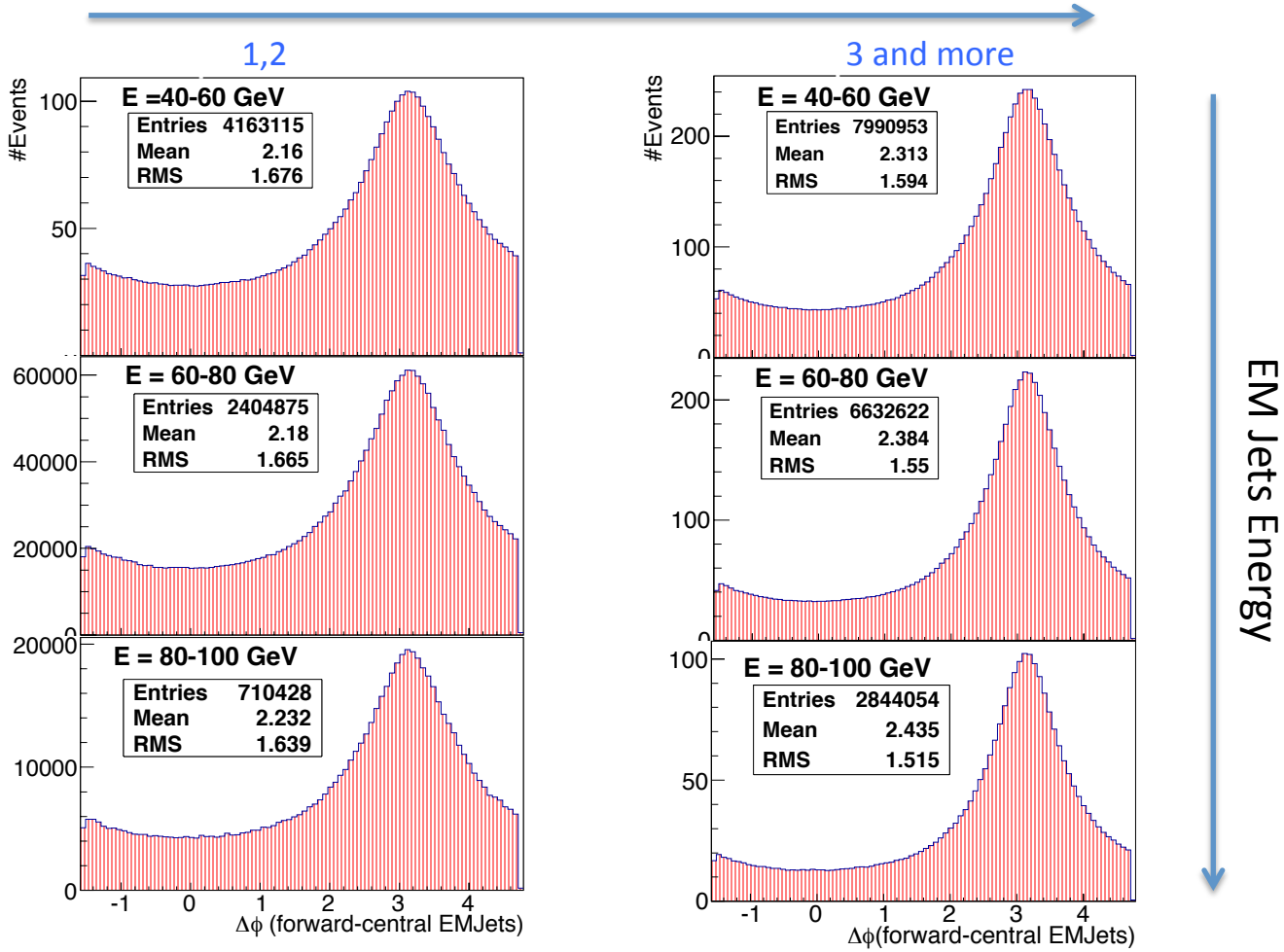
anti-k_T, R = 0.7, $p_T^{EM\text{-}Jet} > 2.0$ GeV/c, $-1.0 < \eta^{EM\text{-}Jet} < 2.0$

Leading central EM-Jets : Jet with highest p_T

- Case-I : having no central jet
- Case-II : having a central jet

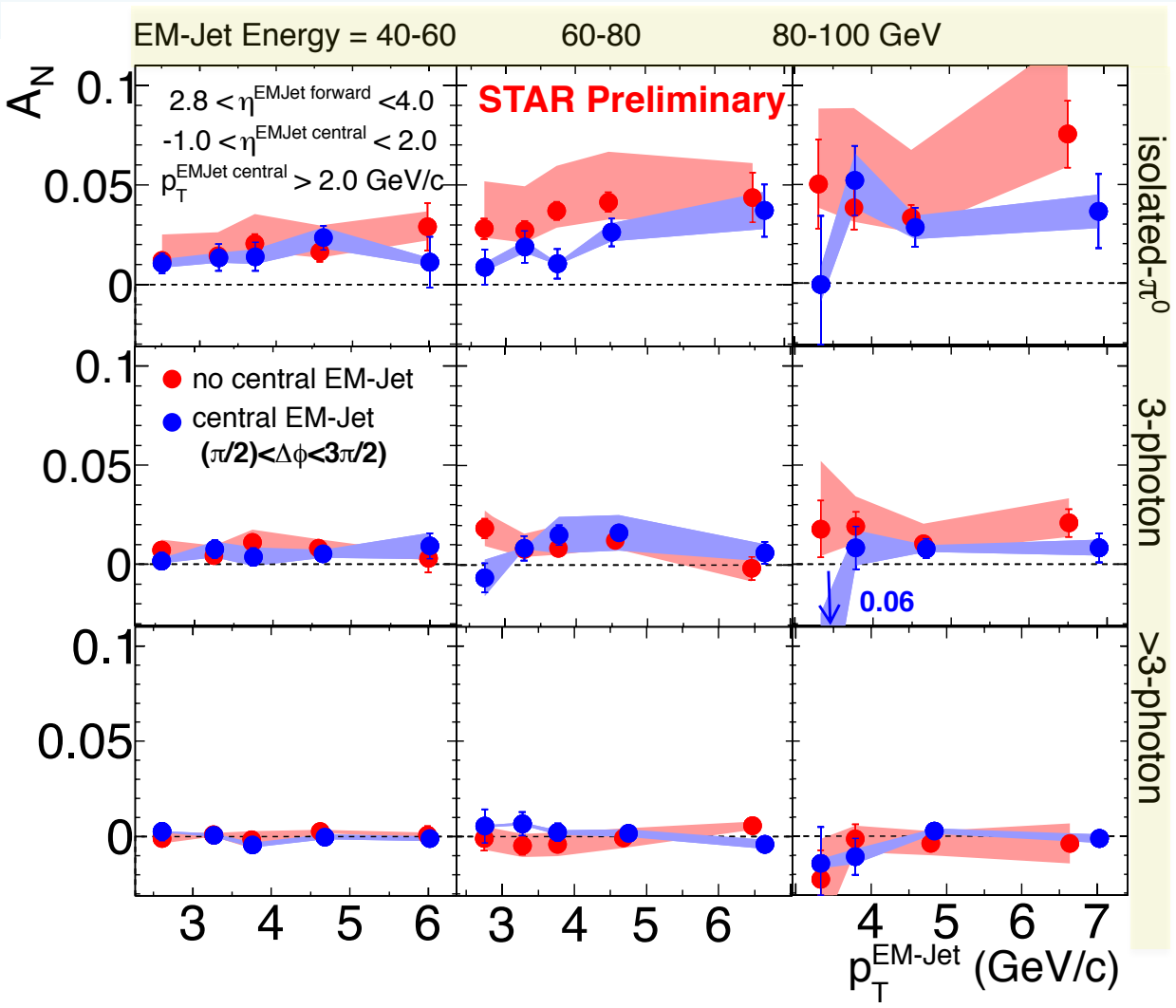
Δϕ correlation between forward and central EMJets

Number of photons for forward EMJets :



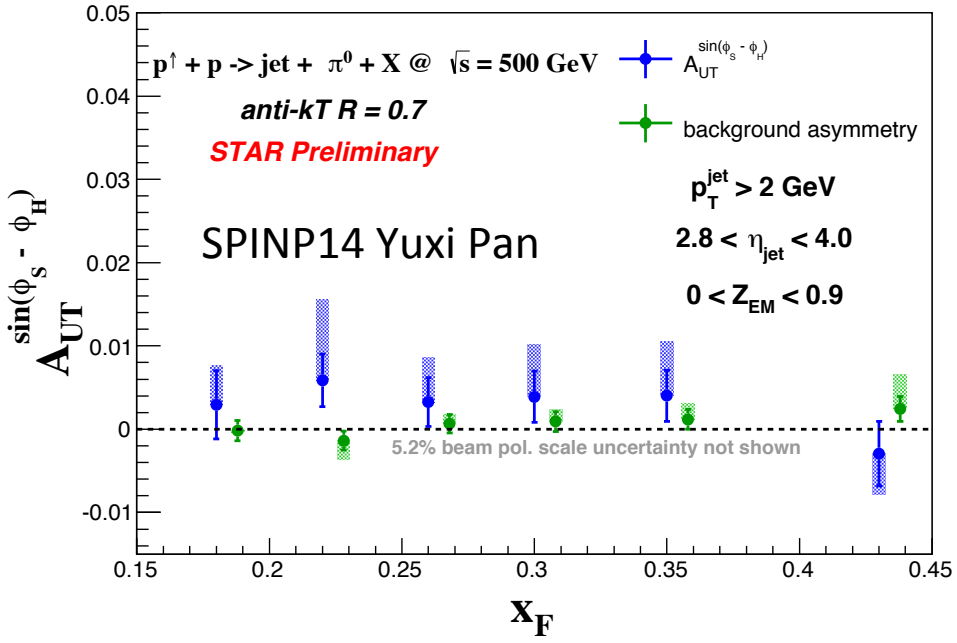
- Correlation is stronger for more N_photon Jets
- For higher EMJets energy, correlation grows stronger

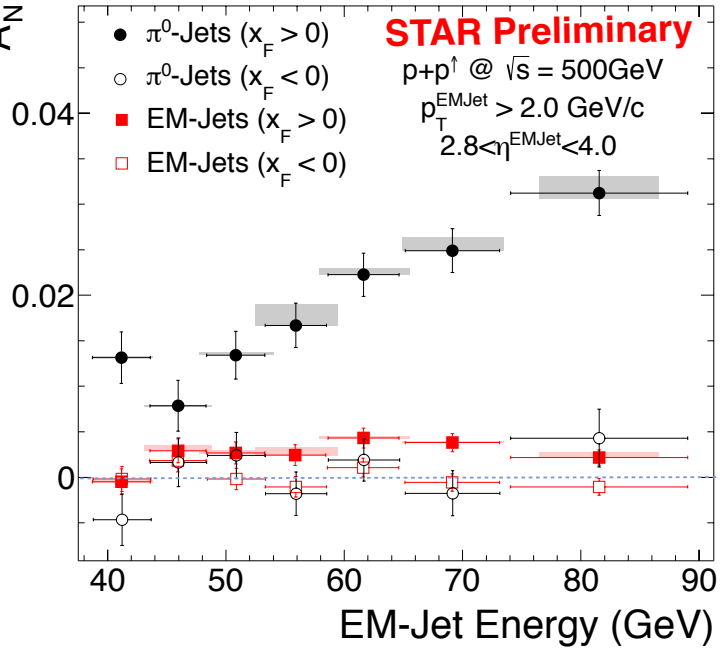
A_N for **correlated central jets** and **no central jet** cases



✧ Asymmetries for the forward isolated π^0 are low when there is a correlated away-side jet.

TMD contributions A_N

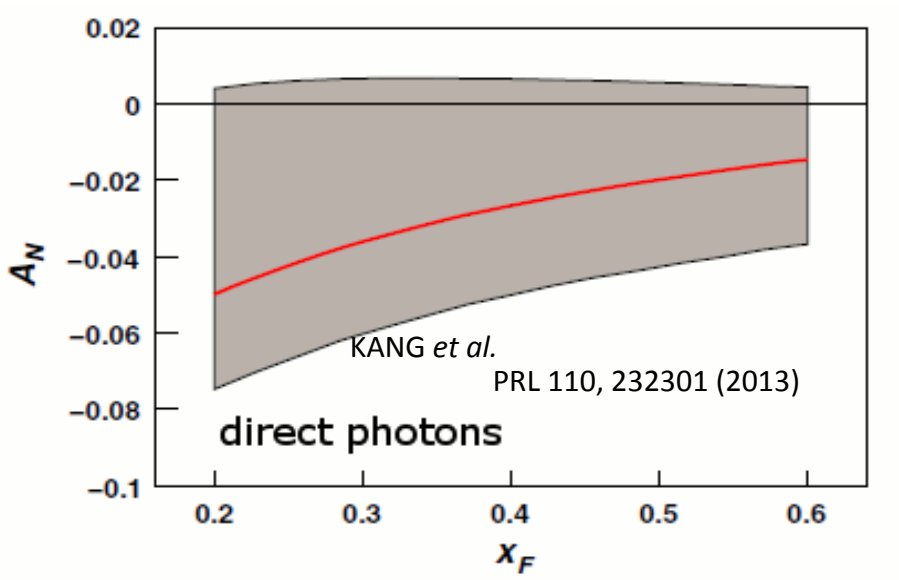


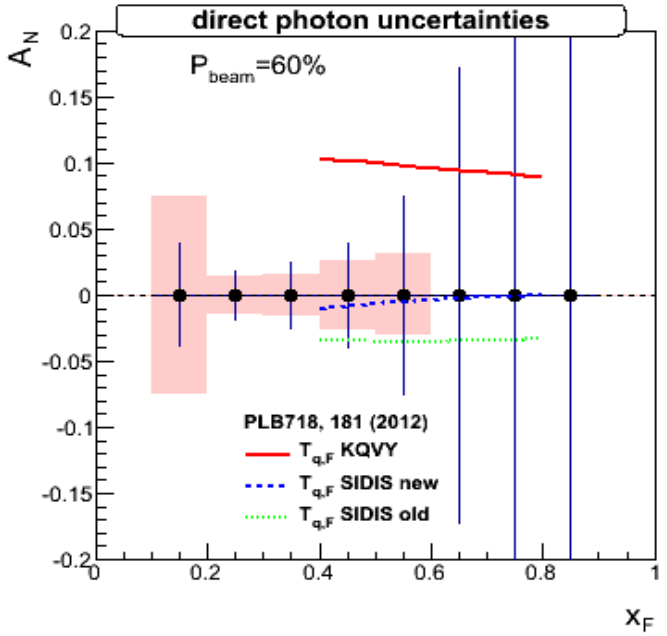


non-zero Collins asymmetries of π^0

γ_{direct} measurements as a test of the twist-3 framework

Observable without fragmentation func. : Drell-Yan, $W^{\pm}$ /Z, jets, direct photons





STAR :
pp 200GeV, L = 40/pb, P=60%

Summary

- EM-jets are reconstructed from photons detected in the FMS at STAR.
- Jets with **isolated π^0 have large asymmetry**.
- **A_N decreases as the event complexity increases**(i.e., the "jettiness")
- Isolated **π^0 asymmetries are smaller when there is a correlated EM-jet** at mid-rapidity.

- **Both of these dependences raise serious question how much of the large forward π^0 A_N comes from 2 → 2 parton scattering (diffractive events?).**

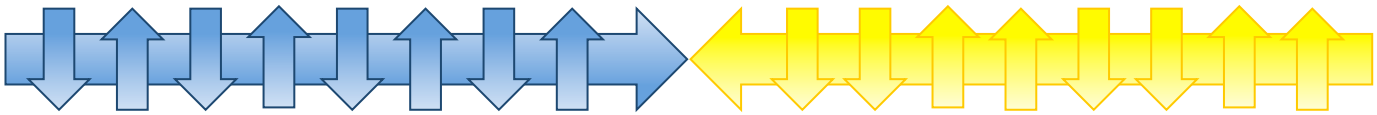
STAR forward goals for data taking on 2015

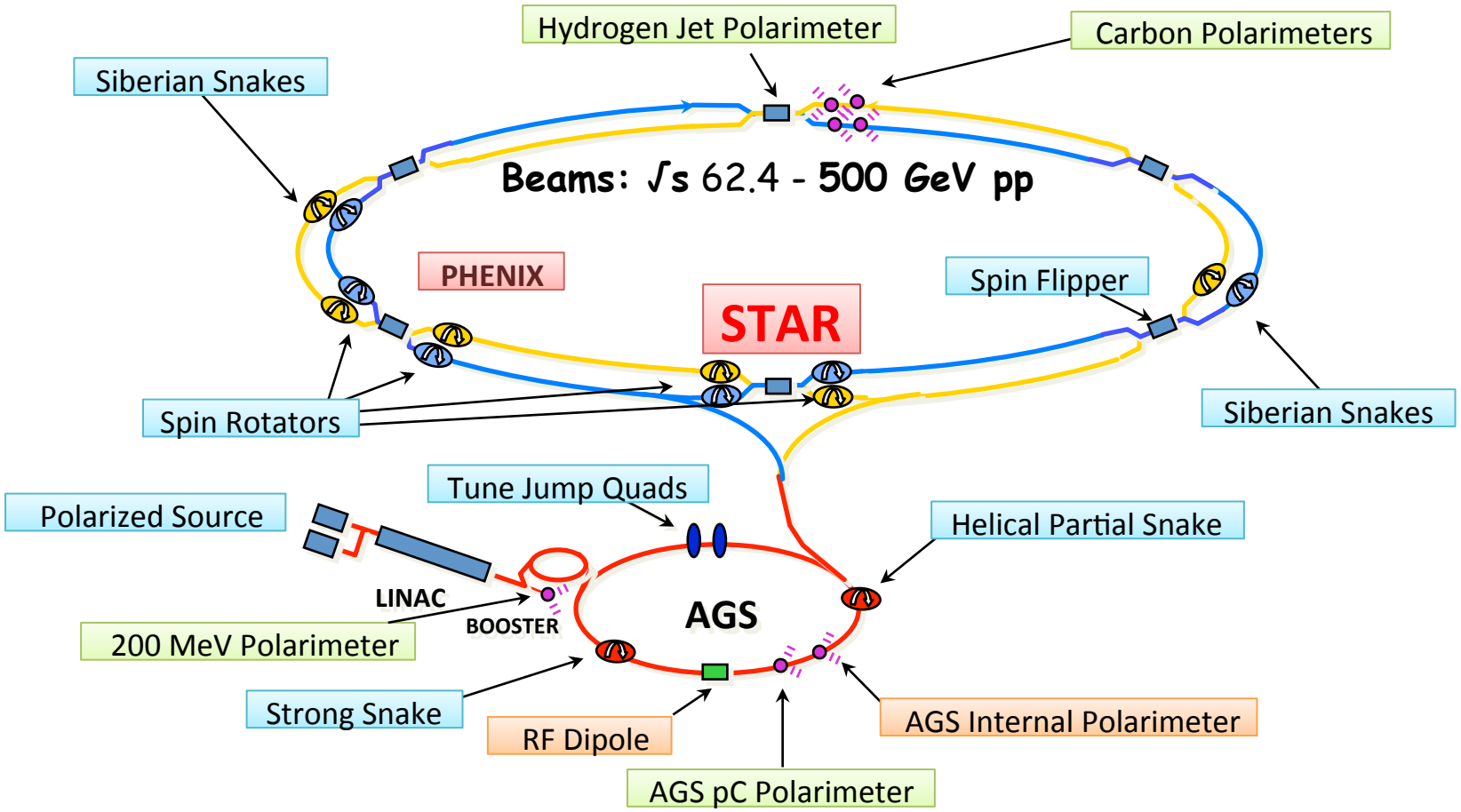
- **Direct Photon** x-section & A_N at pT>2.0GeV (FMS + Pre-shower)
- **Pi0 A_N - Jetty vs Isolated** :
  pp vs pA, diffractive vs non-diffractive (Roman Pots)
- Study di-electron channel (J/psi) towards DY

backups

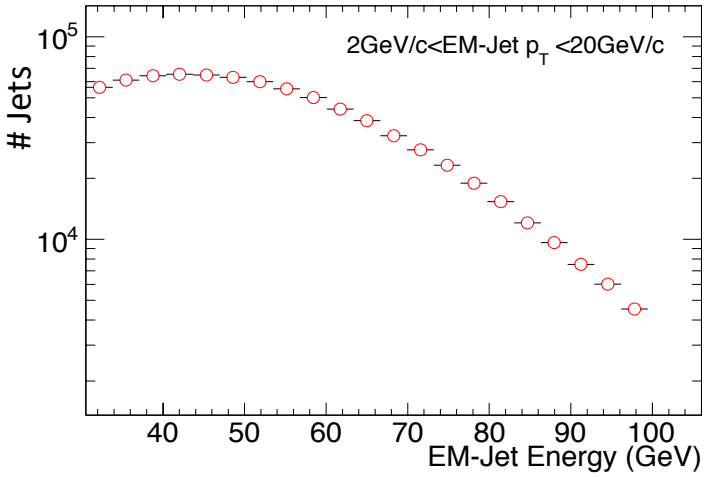
RHIC : the world's first polarized proton collider

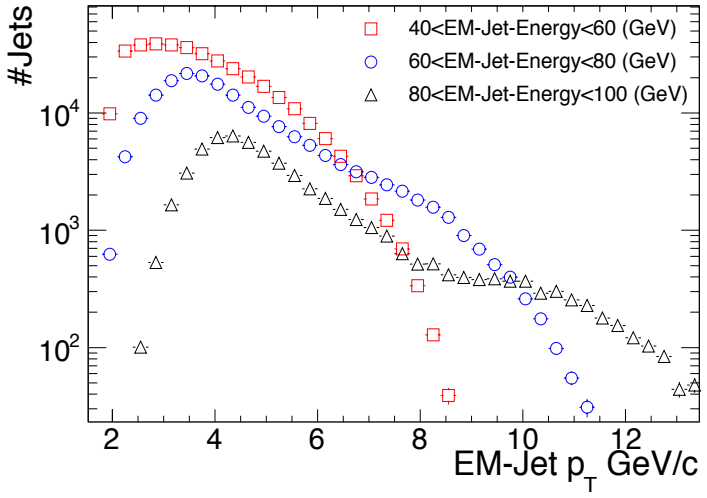
For 2011 : Average Blue Beam Polarization = 51.6% (Transverse), **Luminosity** =22 pb-1





Run-2011 data





p+p √s = 500 GeV transverse datasets

Jet algorithm : anti-kt

R-parameter : 0.7

$p_T^{EM\text{-}Jet} > 2.0$ GeV/c

FMS photons with $p_T >$ 0.001 GeV/c fed into anti-kt

Leading EM-Jets : Multi-photon Jets with highest energy

EM-Jets used to find asymmetry within

$2.8<\eta^{EM\text{-}Jet}<4.0$

40 GeV < $Energy^{EM\text{-}Jet}$ < 100 GeV

Structure in EM-Jet p_T :

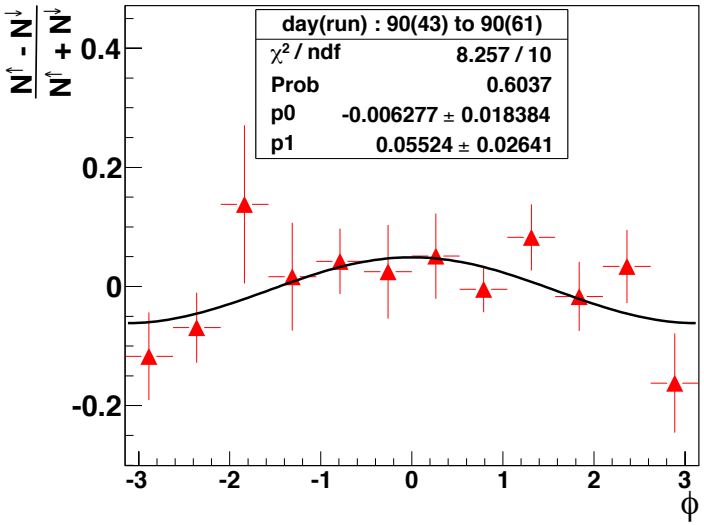
-- Acceptance non uniformity in small and large tower boundary

-- Different trigger threshold influence different p_T region

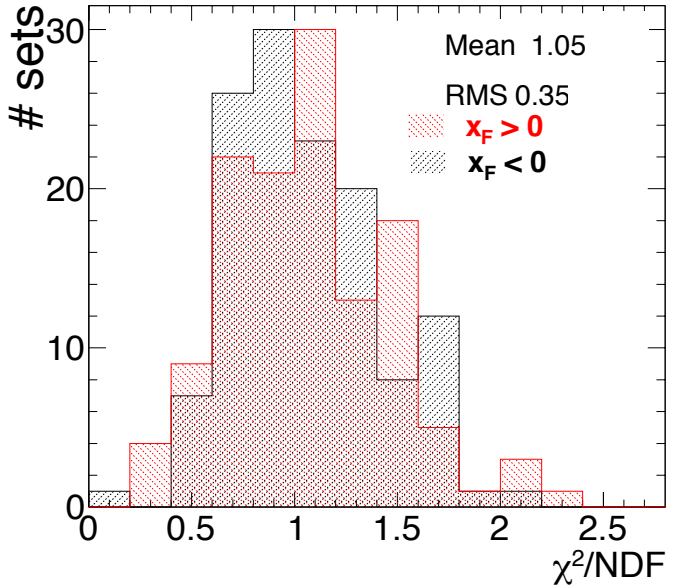
A_N from fits

- A_N is calculated from **p0 + p1 cos(φ)** fits over each fill
  p0 = relative luminosity, **p1** = asymmetry
- A_N's are corrected for polarization values from fill to fill
- Weighted A_N and χ^2/NDF are calculated over entire fills

EM-Jet Energy = 55-57.5 GeV



For 2-photon isolated π^0



Individual point and χ^2/NDF from averages over ~18 fills

SIVERS$|_{DIS}$ = - SIVERS$|_{DY}$

- In p+p, Sivers effect is not Dominantly responsible
- In SIDIS Sivers functions are not well constrained in k_t

Sivers function has opposite sign from that of $T_{q,F}(x, x)$, quark-gluon correlation function

$$\boxed{A(P,\vec{S}_\perp)+B(P')\to C(P_h)+X}$$

$$d\sigma(\vec{S}_\perp) = H \otimes f_{a/A(3)} \otimes f_{b/B(2)} \otimes D_{C/c(2)} + H' \otimes f_{a/A(2)} \otimes f_{b/B(3)} \otimes D_{C/c(2)} + H'' \otimes f_{a/A(2)} \otimes f_{b/B(2)} \otimes D_{C/c(3)}$$

soft gluon poles (SGPs) and soft fermion poles (SFPs)
+ twist-3 effects in the unpolarized proton
+ twist-3 contribution due to parton fragmentation
(two independent FFs. **)**

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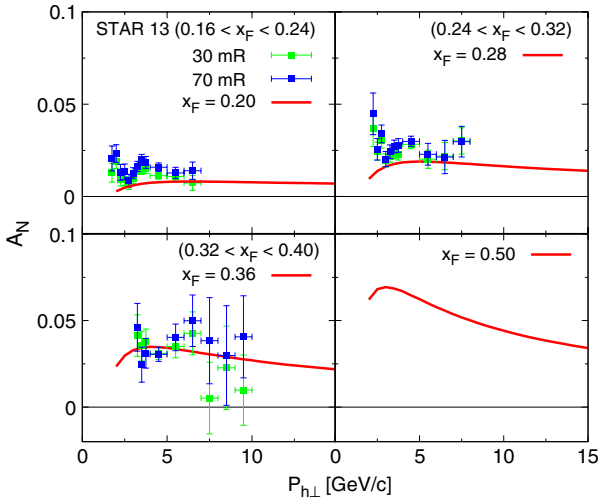

using collinear factorization, $A^{Siv}_{SIDIS} + A^{Col}_{SIDIS} + A^{\cos(2\phi)}_{e^+e^-}$